

# Test of an Optional Strip Posting and Marking Procedure

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A significant part of the en route controllers' job is to post flight progress strips (FPS) next to the plan view display (PVD) and mark the FPSs with new or revised information. The new Display System Replacement (DSR) being implemented in air route traffic control centers (ARTCC) will provide controllers less room to post FPSs. The current experiment tested a new FPS marking and posting procedure designed to reduce the controller's need for, or reliance on, the FPSs.

The experiment was conducted at Cleveland (ZOB) and Jacksonville (ZJX) ARTCCs utilizing individual controllers and controller teams operating in either high or low altitude sectors. In the Normal condition, participants worked as they normally would. During the Optional FPS condition, participants removed FPSs that were not needed after radar contact and communications were established. Also, FPS marking was not required for any information that was recorded elsewhere, such as via computer entry or landline communication.

Participants removed proportionally more FPSs and marked them less often in the Optional FPS condition. There was no effect on performance and participants did not seem to compensate during the Optional FPS condition. On-line measures of workload and post-scenario measures of subjective workload were comparable for the two conditions. Overall, the Optional FPS procedure appeared to be a viable means by which controllers' reliance and use of the FPSs may be reduced.

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## INTRODUCTION

Currently, en route air traffic controllers use paper flight progress strips (FPS) to provide safe and efficient service. The controller uses the FPSs to obtain information about a flight and to record changes in flight parameters such as route, speed, or altitude. Controllers are required by Federal Aviation Administration (FAA) procedures to post FPS for all aircraft within their particular sector of airspace. However, much of the information on the FPSs can be obtained elsewhere, such as from the computer readout device (CRD). Additionally, much of the information that the controller is required to write on the FPSs is also recorded elsewhere, such as on the host computer system or ground-to-air audio tapes. For example, a change in assigned altitude is recorded on audio tape, written on the FPS, entered into the host computer system, and displayed on the plan view display (PVD) in the aircraft's data block. In fact, for legal purposes, all transmissions between the controller and the pilot are recorded on audiotape. Potentially important information for the controller that is not entered into the host computer system or displayed on the PVD includes changes to an aircraft's heading, speed, and issuance of holding instructions. Although redundancy can be very beneficial, particularly when a system fails, redundancy in highly reliable systems<sup>1</sup> may create additional task requirements in terms of workload or cognitive processing for the operator.

The purpose of the current experiment was to examine the performance and workload effects of removing some of the redundant behaviors associated with the FPSs that are required for en route air traffic control (ATC), namely, FPS posting and marking. The outcome is of interest due to impending replacement of workstations used by en route controllers. The old, vacuum tube dependent workstation, or M-1 console, is being replaced by the new, more reliable, Display System Replacement (DSR). The DSR has much more computer power to allow for future system upgrades, including the use of color and additional functions for the controller. One important difference is that the DSR workstation provides less room for FPS management. Therefore, it was reasonable to ask whether the benefits provided by the DSR display and its ability to accommodate new electronic enhancements and tools would be diminished by a restricted ability to use the FPSs. It is important to note that during the initial transition, the DSR will simply replace the old M-1 console without adding any new features. If restricting controller interaction

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<sup>1</sup> ARTCC reliability will improve with the implementation of DSR and with the replacement of the Host computer by the Host/Oceanic Computer System Replacement (HOCSR).

with the FPSs results in a deficit (e.g., poorer performance, higher workload) while using the M-1 console, then a similar deficit may remain during a transition to the DSR.

A number of researchers have emphasized the importance of active FPS usage (e.g., Hopkin, 1988, 1995; Stein, 1991; Stein and Bailey, 1994; Zingale et al., 1992). Hopkin specifically argued that active control procedures are necessary for controllers to maintain a sufficient level of knowledge and situation awareness (SA) during the ATC task. He emphasized the importance of physical interaction such as resequencing or writing on the FPSs. Without such physical interaction, he argued, controller memory, SA, and hence, overall performance, would suffer. The views of Hopkin and others rest on the ideas that memory encoding is important and that it cannot sufficiently occur without such meaningful physical activity. Interviews of 170 controllers throughout the United States indicated that the three memory aids used most by controllers involve the FPSs (Gromelski et al., 1992). These often-used memory aids are FPS management (arrangement of FPSs), offset or tilted FPSs (indication that further action is needed), and FPS marking (updating and confirmation of commands issued).

In a more relevant setting, Zingale, Gromelski, and Stein (1992) provided support for the importance of interaction with the FPSs. These researchers trained aviation students to use TRACON II, a simplified, terminal radar ATC simulator. Participants were provided with an FPS for each aircraft in the simulation. Each participant controlled traffic in both Writing and No-Writing conditions in which they either could or could not record control actions on the FPSs. Results showed that more prior control actions were remembered in the Writing condition than in the No-Writing condition.

The participants used in that study were not air traffic controllers and therefore, the results provide only minimal support for the interactionist position of Hopkin and others. When actual controllers were used, no differences in memory for previously performed actions were found when the same basic experiment was conducted (Zingale et al., 1993). Further evidence contradicting the hypotheses of the interactionist view has been provided by studies that demonstrate a lack of detrimental effects on performance, workload, or cognitive processing when controllers were limited in the amount of interaction they had with the FPSs or when the FPSs were completely removed (Albright et al., 1994; Vortac et al., 1993). The latter observed controllers (FAA Academy Instructors) under both normal and restricted FPS conditions. The FPSs were posted and visible during the restricted condition, however, controllers could not physically manipulate or write on the FPSs. Controller performance, including visual search and recall of flights and flight data, was not impaired by the restricted condition. In fact, controllers were more

likely to remember to grant requests and did so sooner under the restricted condition. They concluded that by restricting interaction with the FPSs, the ATC task was changed such that controllers were then able to assume a more strategic outlook. Restricting interaction with the FPSs resulted in a reduction in workload, or at least a redistribution of workload in regard to the FPSs, and more cognitive resources could be directed towards prospective activities.

Albright, Truitt, Barile, Vortac, and Manning (1995) previously examined the role of the FPSs by observing how controllers compensate for the absence of the FPSs. They observed full performance level, en route controllers in a simulated, high altitude sector during both a normal condition and a condition in which all FPSs were removed. By removing all FPSs from the controllers and giving them a notepad on which to write anything they wished, Albright et al. were able to observe whether controllers could compensate for the lack of FPSs and—if so—how they compensated. A subject matter expert (SME) evaluated controllers' performance and controllers provided subjective workload ratings after each scenario. Results showed no differences in performance or perceived workload when the FPSs were absent. Controllers compensated for the lack of FPSs by performing more flight plan readouts on the computer system. The flight plan readout (FPR) provides the same information as does an FPS<sup>2</sup>. Although this means of accessing flight information appeared to have slowed the time it took controllers to grant a request when FPSs were absent, controllers spent significantly more time watching the PVD. Given the results of Vortac et al. (1993) and the way in which controllers compensated for the absence of FPSs in the Albright et al. study, one can argue that a primary function of the FPSs is to provide ready access to flight information and, in terms of ultimate performance and memory, very little benefit is provided by writing on the FPSs.

The results of Vortac et al. (1993) and Albright et al. (1995) suggest that, given the physical limitations of the DSR and the space allotted for the FPSs, it may be practical to reduce the amount of writing on the FPSs and the number of FPSs that must be posted. Currently, en route controllers are required to post an FPS for an aircraft from the time radar contact and communications are established with that aircraft until the controller instructs the aircraft to switch radio frequencies and contact the next controller. These requirements result in at least one FPS being posted for each aircraft in a controller's airspace. Furthermore, many control actions must be recorded on the

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<sup>2</sup> The FPR provides the aircraft's computer identification number, callsign, type and equipage, assigned beacon code, ground speed, transition fix, estimated time over transition fix, requested altitude, filed route, and destination.

FPSs as per the FAA Air Traffic Controller Handbook, 7110.65J (1995).

Reducing the requirements for FPS marking and posting by making them optional to the controller thus should not prevent the controller from achieving adequate performance while working within the current specifications of the DSR. Reducing the FPS requirements eliminates the redundant recording of information and potentially results in fewer FPSs that the controller must post and search through in order to find important information. However, the evidence in support of reduced FPS marking and posting is somewhat limited. The Vortac et al. (1993) study was limited to individual controllers who were instructors at the FAA Academy. Although Albright et al. (1995) used field controllers, their results are also limited in that they only observed individual controller behavior in a single, high altitude sector. In order to provide further support for the viability of the reduction of FPS posting and marking, questions similar to those asked by Vortac et al. and Albright et al. must be addressed in a variety of both high and low altitude sectors. Furthermore, results must be generalizable beyond the individual controller, and the impact of reduced FPS activities must be assessed for the en route air traffic control team as well.

The current experiment was designed to answer two basic questions: First, does providing controllers with the option of posting and marking FPSs result in significantly fewer FPS postings and markings? Second, if the optional posting and marking of FPSs does result in fewer FPSs being posted, what, if any, are the effects on controller performance and workload? To answer these questions, participants were observed under both Normal and Optional FPS Marking/Posting conditions. During the Normal condition, controllers had full use of the FPSs and they controlled traffic as they usually would. Under the Optional FPS condition, with some exceptions, controllers had to post and mark FPSs only until radar contact and communications were established and accepted with an aircraft.

The procedures used in the Optional FPS condition were developed by The Strip Reduction Working Group, which met initially from November 4-6, 1997, in Washington, D.C. The sole purpose of the meeting was to identify ways to reduce en route controllers' use of FPSs and FPS marking in anticipation of the DSR upgrade. The group was organized by the FAA Air Traffic Operations (ATO) branch and included representatives from ATO-110, the Civil Aeromedical Institute, the National Air Traffic Controller's Association (NATCA), the ATC Supervisors Committee, and the University of Oklahoma. The varied composition of the Strip Reduction Working Group allowed for consideration of many possibilities for the reduction of FPS activity. The group discussed and recommended changes to the current FPS procedure as possible ways to reduce FPS activity. The

result of the group's effort was an alternative FPS procedure that is shown in Appendix A. An important point of the revised FPS procedure is that although it allows for a reduction in the posting and marking of FPSs, such a reduction is optional and would only be used if the controller(s) responsible for a sector decided to do so. Before adjourning, the Strip Reduction Working Group decided that an empirical study would be appropriate to test the revised FPS procedure.

The experiment was conducted at two Air Route Traffic Control Centers (ARTCC), Cleveland (ZOB) and Jacksonville (ZJX)<sup>3</sup>. Data on performance and workload were collected from individual controllers and controller teams operating in either high or low altitude sectors.

## METHOD

### Participants

A total of 48 full performance level (FPL) controllers volunteered to participate in the experiment (ZOB = 24, ZJX = 24). Just prior to the experiment, each controller read and signed an informed consent statement and then completed a biographical questionnaire. Mean responses to the biographical questionnaire are shown in Table 1. Controllers participated either individually or as part of a two-person team. Controller teams are generally made of two people; one person (the R-side) is primarily involved with activities associated with the radar screen while the second person (the D-side) is mainly involved

**Table 1. Means and Standard Deviations for Biographical Data by ARTCC**

Biographical Info	ARTCC	
	ZOB	ZJX
Number of ARTCCs worked	1.17 (0.38)	1.17 (0.38)
Years in current area	10.37 (7.01)	10.75 (7.04)
Years at current ARTCC	11.28 (6.73)	11.86 (6.56)
Years as FPL	8.94 (6.91)	11.15 (8.07)
Years as Controller	13.66 (6.49)	15.30 (6.84)
Years since recertification	4.91 (4.60)	7.89 (7.77)
Age	38.46 (6.38)	39.13 (6.65)

<sup>3</sup> Additional data focusing on individual controllers in low altitude sectors were collected at Boston (ZBW). Because there was no effect of the experimental manipulation at ZBW, and because these data focused on individuals in low altitude sectors only, these data are not presented here.

with posting and marking the FPSs. The D-side also handles the transfer of information to, and the recording of information from, other sectors and ARTCCs.

### **Scenarios**

For each ARTCC, two scenarios were developed for each sector (high or low altitude) and staffing condition (individual or team) for a total of eight scenarios per ARTCC. All scenarios were selected from training scenarios that had been developed previously by the training department of each ARTCC. Once selected, scenarios were altered if necessary to meet the complexity requirements of the experiment or to ensure the occurrence of particular events of interest. Sectors used at ZOB were Hudson (high altitude) and Lichtfield (low altitude). Sectors used at ZJX were Brewton (high altitude) and Florence (low altitude). All scenarios were designed to be at least 30 minutes in length. Scenarios for individual controllers had a complexity rating of 70% and scenarios for controller teams had a complexity rating of 100%. Complexity ratings were calculated by the ARTCC's training specialists and were based on the number and type of events that occurred during each scenario.

Among the typical occurrences of each scenario, a strip-critical event was identified in order to give the SME an opportunity to evaluate how each event was handled, especially when the related FPS had already been removed from the board. Each strip-critical event required the controller to make use of an FPS and was particular to the scenario in which it occurred. Strip-critical events included, 1) providing holding instructions, 2) a pilot requesting a route change, 3) an aircraft flying at wrong altitude for direction of flight, and 4) an aircraft requiring special handling such as Air Force One.

### **Dynamic simulator (DYSIM) training facility**

The DYSIM is a high fidelity simulation facility that closely resembles the real en route ATC environment. Workstations are fully functional and landline communications are provided. Flight plans for each aircraft in a scenario are pre-programmed, but controllers or simulation pilots may change any flight plan during the simulation. Training specialists execute ATC instructions to simulate the roles of pilots and other controllers during the simulation.

### **Workload Assessment Keypad (WAK)**

The WAK is a computer-controlled, on-line subjective measure of workload. The WAK is well adapted for use in the field because it is

relatively small, portable, and can collect ratings from as many as four participants simultaneously. Based on the work of Stein (1985), the WAK obtains a workload rating by aurally and visually prompting the participant. At an adjustable interval, the WAK emits a high-pitched tone and its seven, numbered buttons illuminate. The participant then makes a rating by pressing one of the buttons within a specified amount of time. The WAK records each rating as well as elapsed time from prompt to response.

### **Task Load Index (TLX)**

A modified version of the NASA TLX (Hart and Staveland, 1988) was used to collect subjective ratings of taskload. The TLX contains six separate scales to assess mental demand, physical demand, temporal demand, effort, frustration, and performance. Each scale was represented as a 100-mm line, anchored from low to high. Participants placed an "X" on each scale after an experimenter described what the scale was intended to measure.

### **PROCEDURE**

The procedure was the same for both ARTCCs. All data were collected in the DYSIM training facility of the respective ARTCC. Following instructions, data collection began with the first of two scenarios. The first scenario was always the Normal condition in which participants were asked to control traffic as they normally would. The two scenarios corresponding to group (individual or team and high or low altitude sector) were counterbalanced, such that each scenario appeared in each condition an equal number of times. Thus, any differences between the Normal and Optional FPS conditions could not be due to differences in scenarios. Participants were given a notepad to record anything they wished. The scenario began with the SME providing a position relief briefing and then the participant took full control of the scenario for 30 minutes.

During the scenario, the WAK prompted the participant every 5 minutes for a workload rating (where 1 = very low workload and 7 = very high workload). The SME used a behavioral event checklist to record the occurrence of specific events related to controller performance including operational errors, operational deviations, missed handoff, violation of a Letter of Agreement or other directive, missed readback error, failure to grant request, failure to direct aircraft to switch radio frequencies, cause unnecessary delay, inappropriate request of information, computer entry error, and failure to complete proper coordination. The SME also observed one strip-critical event



(for example, pilot requests route change) and noted if the participant effectively handled that event. For controller teams, communication effectiveness was evaluated by the SME using a form to note whether participants were aware of each other's actions, if duplicate actions were performed, or if lack of communication affected safety or efficiency in any way.

Two experimenters used microcassette recorders to archive activity relevant to the PVD, CRD, and FPSs. In addition, experimenters recorded the time at which each activity occurred. One experimenter recorded the type of actions performed by the controller involving the PVD and CRD and the time these actions were performed. These actions included request for information, use of a route display, J-ring<sup>4</sup>, /0<sup>5</sup>, and FPR. The second experimenter recorded the callsigns on FPSs and the times each was posted and removed. The second experimenter also recorded D-side activities regarding the PVD and D-side CRD when controller teams were being observed. At the end of the first scenario, the participant(s) used a list that was displayed on the CRD to provide a position relief briefing to the SME. Once completed, the SME evaluated the quality of the briefing. The participant then completed the TLX which was followed by a 15-minute break.

Participants returned to the DYSIM after the break. Before starting the Optional FPS condition an experimenter reminded the participants how to use the WAK. A representative of NATCA then summarized the proposed strip marking and posting procedure. Under the Optional FPS condition, controllers were instructed by the NATCA representative that they were to post and mark FPSs only until radar contact and communications were established and accepted with an aircraft. After that, FPS activity should follow the optional posting and marking procedure. Participants placed a check mark in field 21-24 of an FPS to indicate that optional posting and marking could be used for that strip. However, optional marking only applied to information that was recorded elsewhere, for example, by computer entry or voice recordings. The NATCA representative also instructed participants that information that was not redundant had to be recorded on the FPSs and that an FPS could be removed from the board if it was no longer needed. Participants were also instructed that an FPS was required to be posted and marked in special

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<sup>4</sup> A J-ring (also referred to as a distance reference indicator) is displayed on the PVD as an approximate circle that can be placed around selected aircraft for means of determining horizontal separation.

<sup>5</sup> A "slant zero", /0, is an action performed by the controller via keyboard entry to shorten the length of a leader line (the line connecting an aircraft position symbol with a datablock as displayed on the PVD). Many, but not all, controllers use the /0 entry as an indicator, or reminder, that they have instructed an aircraft to switch radio frequencies.

situations which included, 1) radar contact would be lost, 2) an aircraft was transitioning from radar to non-radar, 3) special handling was required, 4) non-radar flight, 5) an aircraft transitioning from auto to non-auto mode, and 6) holding instructions issued. The full text of the Optional FPS procedure is shown in the Appendix. Finally, participants were encouraged (but not required) by the NATCA representative to follow the optional FPS posting and marking procedures as best they could so that an adequate test of the procedure could be conducted. Experimenters then provided each participant with a Procedures Summary Sheet and reviewed each item on the sheet with the participant. As in the Normal condition, a notepad was provided for the participant to record anything he or she wished.

Once the participant indicated that he or she understood the instructions, the Optional FPS condition began with a position relief briefing from the SME after which the participant took full control of the scenario for 30 minutes. As before, the SME and two experimenters observed the participant's activity, and participants were prompted by the WAK every 5 minutes for a workload rating. The participant used a list that was displayed on the CRD to provide a position relief briefing at the end of the scenario and then completed the TLX a second time. After responding to the second TLX, participants completed a post-experimental questionnaire. Finally, participants were debriefed, thanked, and excused.

## RESULTS

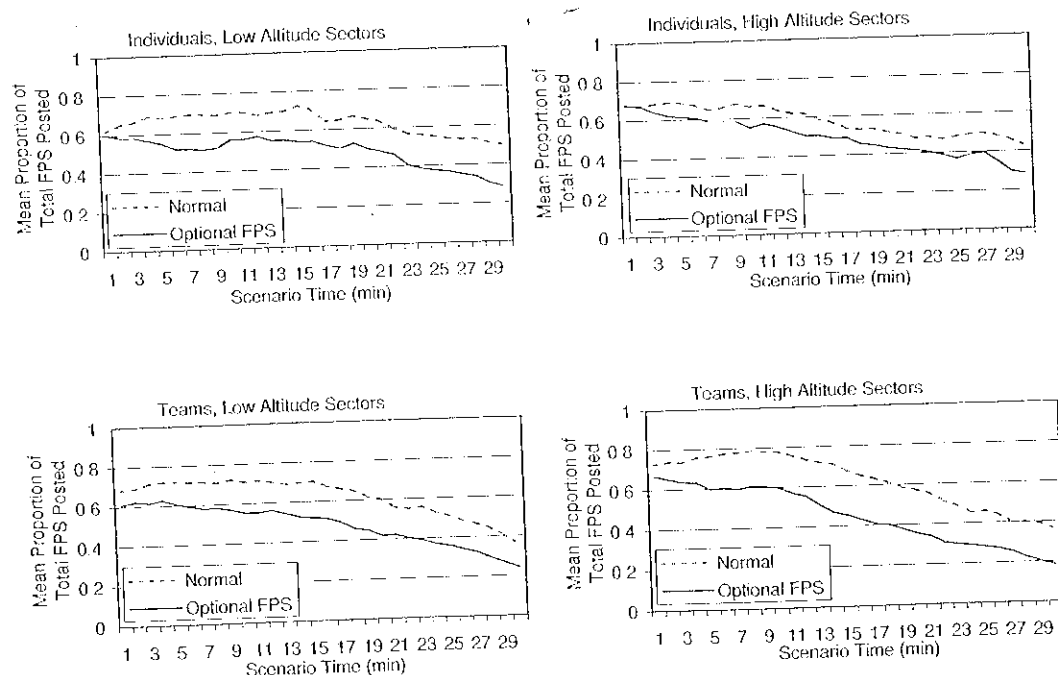
There were no apparent differences between the data from ZOB and ZJX so these data were combined, yielding a total of 16 individuals (8 per sector type) and 16 teams (8 per sector type) for the analysis. Results of individuals and teams will be reported separately for each sector type. Evaluative comparisons will not be made between ARTCCs, individuals and teams, or high and low altitude sectors because the objective of this experiment was to evaluate the Optional FPS procedure, not to evaluate a particular facility. It should be noted that scenarios were used an equal number of times in each condition. Therefore, any differences between the Normal and Optional FPS conditions were not due to differences in scenarios. Statistical values are only reported for tests that were significant at a level of  $\alpha < .05$ . Finally, in the following exposition, if analyses for each combination of staffing and sector type yielded identical conclusions, only the means collapsed across these factors are presented. If, on the other hand, one combination of staffed sector-type did not agree with the others, the means for each sector and staffing condition are presented.

## Proportion of total FPS posted

It would be difficult to assess the reduced posting and marking procedure without some willingness of the participants to try the new procedure. An examination of the proportion of total FPSs that could have been posted during the scenarios provides information regarding whether or not participants were willing and able to follow instructions and if in fact the Optional FPS procedure resulted in fewer FPSs being posted over time. Figure 1 shows the mean proportion of total FPSs posted by condition and scenario time for individuals and controller teams in both high and low altitude sectors.

Each of the four datasets was analyzed using a 2 (Normal vs. Optional FPS)  $\times$  30 (1-min intervals) repeated measures analysis of variance (ANOVA). When analyzing the proportion of FPSs posted, individuals in the low altitude sectors posted proportionally fewer FPSs in the Optional FPS condition ( $M = 0.49$ ,  $SD = 0.15$ ) than in the Normal condition ( $M = 0.64$ ,  $SD = 0.16$ ), and posted fewer FPSs over time,  $F(1, 7) = 15.50$  and  $F(29, 203) = 14.13$ , respectively. There was a significant Condition  $\times$  Time interaction,  $F(29, 203) = 4.71$ . Individuals in the low altitude sector were able to use the Optional FPS procedure to reduce the proportion of FPSs posted during the first few minutes of the scenario and then retained that reduction.

Individuals in high altitude sectors posted proportionally fewer FPSs in the Optional FPS condition ( $M = 0.50$ ,  $SD = 0.18$ ) than in the Normal condition ( $M = 0.58$ ,  $SD = 0.19$ ),  $F(1, 7) = 23.92$ , and the



**Figure 1.** Mean proportion of FPS posted for each staffing condition and each sector type.

number of FPSs posted declined over time,  $F(29, 203) = 3.15$ . The Condition  $\times$  Time interaction was not significant indicating that the proportional reduction was relatively immediate and was retained throughout the scenario. Individuals in high altitude sectors were able to implement the Optional FPS procedure in that they were able to post proportionally fewer FPSs in the Optional FPS condition than in the Normal condition.

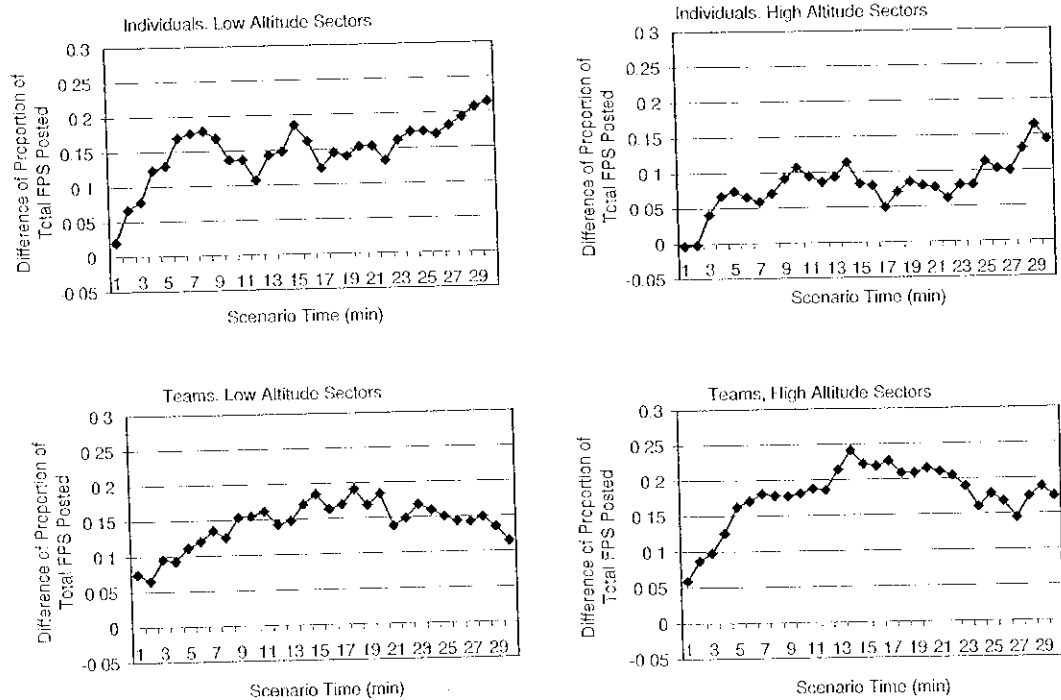
Controller teams in low altitude sectors posted proportionally fewer FPSs in the Optional FPS condition ( $M = 0.48$ ,  $SD = 0.16$ ) as compared to the Normal condition ( $M = 0.62$ ,  $SD = 0.17$ ),  $F(1, 7) = 8.36$ , and also posted fewer FPSs over time,  $F(29, 203) = 14.72$ . The Condition  $\times$  Time interaction was also significant,  $F(29, 203) = 6.86$ . Therefore, teams in low altitude sectors used the Optional FPS procedure to reduce the proportion of FPSs that were posted early in the scenario relative to the Normal condition. Although this reduction took some time, the reduction was maintained after the first few minutes of the scenario.

Controller teams in high altitude sectors posted proportionally fewer FPSs in the Optional FPS condition ( $M = 0.45$ ,  $SD = 0.16$ ) than in the Normal condition ( $M = 0.62$ ,  $SD = 0.17$ ), and posted fewer FPSs over time,  $F(1, 7) = 81.19$  and  $F(29, 203) = 39.09$ , respectively. There was a significant Condition  $\times$  Time interaction,  $F(29, 203) = 8.36$ . Similar to teams in low altitude sectors, teams in high altitude sectors also were able to use the Optional FPS procedure to reduce the proportion of FPSs posted during the first few minutes of the scenario and then retained that reduction. Controller teams in both high and low altitude sectors removed FPSs at a greater proportional rate during the Optional FPS condition. Overall, participants were able to post proportionally fewer FPSs during the Optional FPS condition as compared to the Normal condition.

A significant main effect of Time was found for all four groups of participants. That is, proportionally fewer FPSs were posted over time regardless of condition (Normal or Optional FPS). This effect is best explained by the fact that the scenarios tended to involve fewer aircraft as they progressed. Because the scenarios were designed to be 30 minutes in length, new aircraft were not being generated towards the end of the scenarios and hence, the number of FPSs that were posted tended to decrease over time.

Difference scores were calculated to simplify inspection of the graphs. Difference scores were calculated for each group of participants by subtracting the proportion of FPSs posted in the Optional FPS condition from the proportion of FPSs posted in the Normal condition for each minute of the scenario. These data are shown in Figure 2.

Overall, the difference scores show that the reduction in the proportion of FPSs posted in the Optional FPS condition as compared to



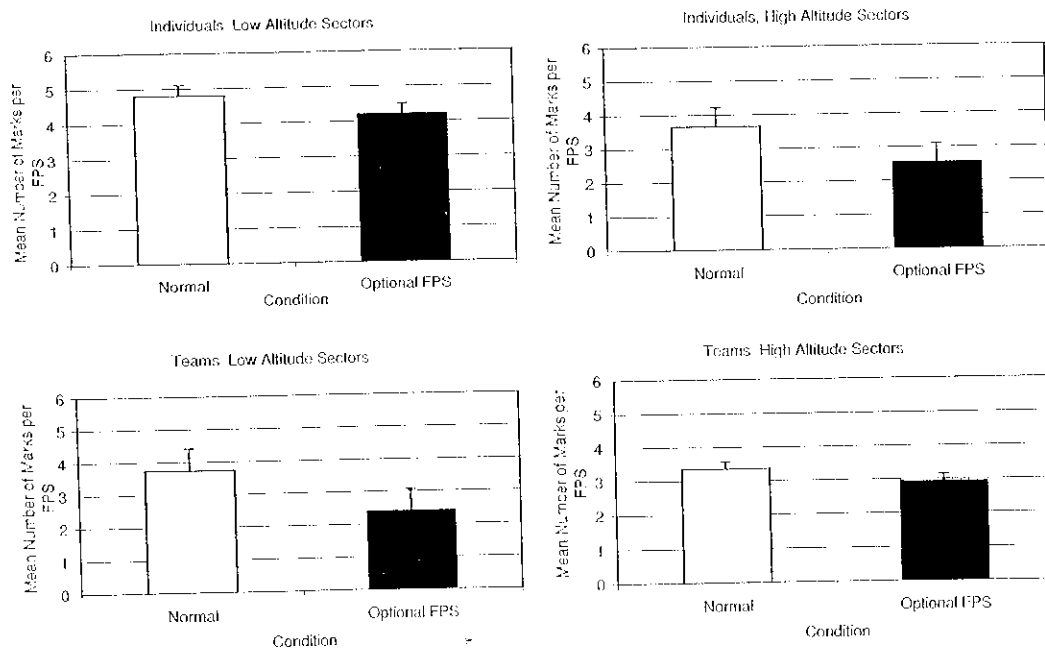
**Figure 2.** Mean difference scores of proportion of total FPS posted for each staffing condition and each sector type.

the Normal condition occurred relatively early in each scenario. The difference in the proportion of FPSs posted was then maintained (for individuals) or increased (for teams) throughout the scenarios. Individuals in the high altitude sectors showed the smallest difference in the proportion of FPSs posted. Even in this condition it was a significant reduction of 5% to 15% fewer FPSs posted in the Optional FPS condition as compared to the Normal condition. The greatest reduction in the proportion of FPSs posted was realized by the controller teams in the high altitude sectors who posted at times a difference greater than 20% fewer FPSs in the Optional FPS condition.

### Number of marks per FPS

In addition to observing how many FPSs were posted, the average number of marks made on each FPS were also counted. Again, this ensured that participants were in fact using the optional marking procedure as instructed. Participants did in fact make about 1 less mark per FPS in the Optional FPS condition than in the Normal condition. Data are shown in Figure 3.

Data were analyzed using a dependent t-test for each data set. Individuals in low altitude sectors made significantly fewer marks in the Optional FPS condition ( $M = 4.19$ ,  $SD = 0.20$ ) than in the Normal condition ( $M = 4.8$ ,  $SD = 0.15$ ),  $t(1, 7) = 2.64$ . Individuals in



**Figure 3.** Mean number of marks per FPS for each staffing condition and each sector type.

high altitude sectors also made significantly fewer marks per FPS in the Optional FPS condition ( $M = 2.52$ ,  $SD = 0.10$ ) than in the Normal condition ( $M = 3.65$ ,  $SD = 0.13$ ),  $t(1, 7) = 3.05$ . Thus, individuals in both low and high altitude sectors made significantly fewer marks on the FPSs in the Optional FPS condition as compared to the Normal condition.

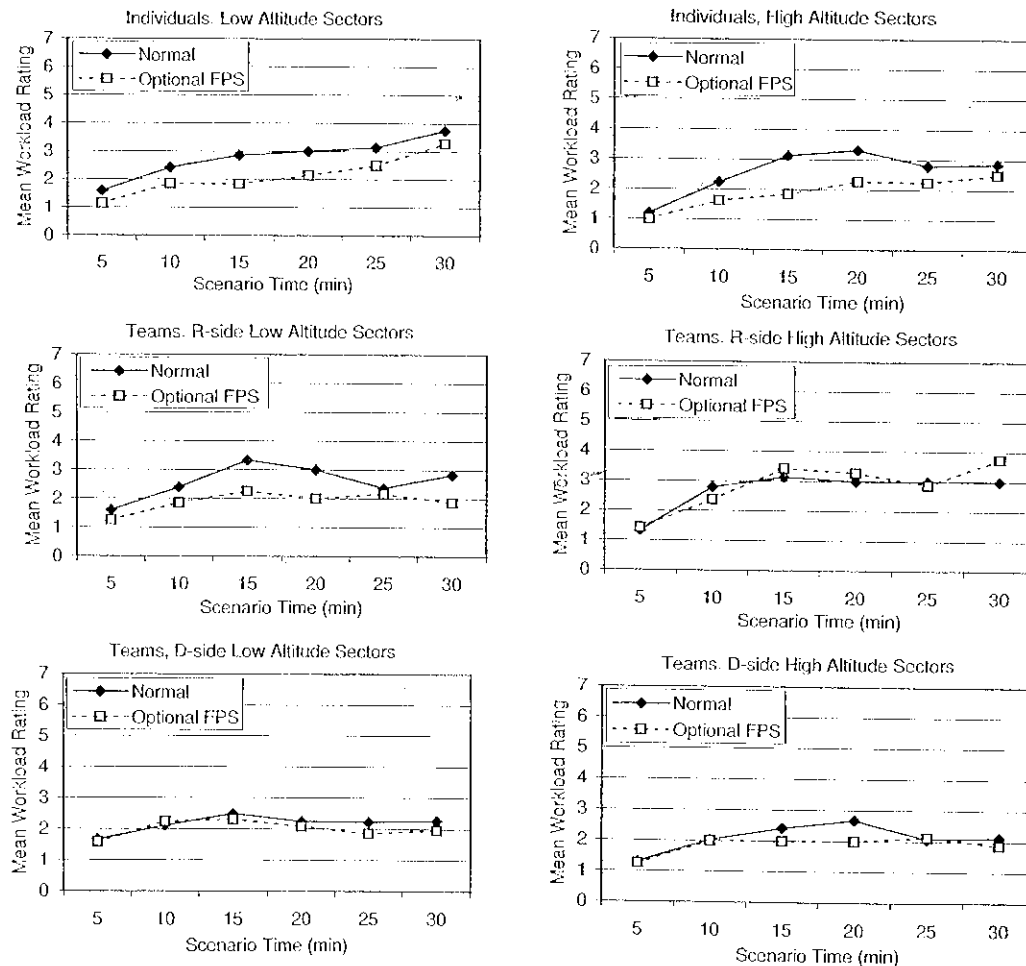
Controller teams in low altitude sectors made significantly fewer marks in the Optional FPS condition ( $M = 2.39$ ,  $SD = 0.11$ ) as compared to the Normal condition ( $M = 3.74$ ,  $SD = 0.49$ ),  $t(1, 7) = 3.19$ . Controller teams in high altitude sectors made a comparable number of marks per FPS in the Optional FPS condition ( $M = 2.93$ ,  $SD = 0.07$ ) and the Normal condition ( $M = 3.35$ ,  $SD = 0.19$ ). With the exception of teams in high altitude sectors, participants made fewer marks on the FPSs under the Optional FPS condition. This result, together with the FPS posting result, supports the fact that participants were implementing the experimental procedure.

### On-line workload ratings

It was expected that on-line ratings of workload using the WAK would be lower during the Optional FPS condition due to the reduced board management responsibilities. Alternatively, the introduction of a new procedure could produce more board management duties and hence, more workload. Missing data due to a participant not responding to a single WAK prompt were replaced by the appropriate

group mean. Replacement by group means artificially reduces variance.<sup>6</sup> All controllers were included in the analysis even if they failed to respond to more than one WAK prompt. Each of the 6 datasets was analyzed separately using a 2 (Normal vs. Optional FPS)  $\times$  6 (5-min intervals) repeated measures ANOVA.

The results are shown in Figure 4. In virtually every condition (with the exception of D-side controllers in low altitude sectors) workload increased over time. More important are the comparisons of the Optional and Normal FPS conditions. Individual controllers in low altitude sectors rated workload as being significantly lower in the Optional FPS condition,  $F(1, 7) = 23.69$ , as did individual controllers in high altitude sectors, but this latter difference was not significant.



**Figure 4.** Mean on-line workload rating for each staffing condition and each sector type.

<sup>6</sup> The replacement of missing data in subjective workload measurement remains an unresolved procedural issue. It is preferable to replace missing WAK data with group means rather than with a maximum workload rating because it was likely that a failure to respond was due to inadequate auditory and visual prompts rather than extremely high workload.

R-side controllers in low altitude sectors perceived workload as being less on average in the Optional FPS condition, but not significantly so. Likewise, R-side controllers in high altitude sectors rated the Normal and Optional FPS conditions as being similar in workload. D-side controllers in both low and high altitude sectors rated workload as being comparable under the two FPS procedures.

Overall, participants tended to rate workload as low to moderate and judged workload in the Optional FPS condition as being comparable and occasionally lower than in the Normal condition.

### Post-scenario TLX ratings

Participants provided another subjective rating of workload after each scenario by completing the TLX. The TLX ratings were analyzed separately for each group of participants (Individual, R-side, and D-side in both high and low altitude sectors) using a 2 (Optional FPS vs. Normal)  $\times$  6 (TLX item) multivariate analysis of variance (MANOVA). None of the omnibus multivariate analyses were significant and no further analyses were pursued. Mean results are shown in Figure 5. The TLX results only suggest weak relationships in the data and were not supported by statistical analyses. If anything, the overall TLX ratings favor the Optional FPS procedure.

### Compensatory behaviors

Participants could have written on the notepad to compensate for marking the FPSs less often. However, participants wrote on the

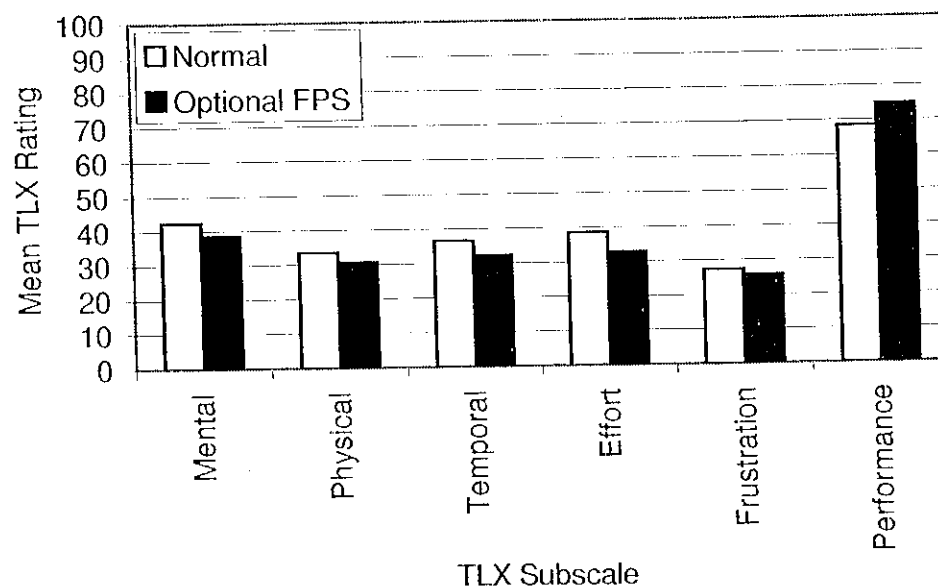


Figure 5. Mean TLX rating collapsed over staffing conditions and sector types.



notepad infrequently. Participants made a comparable number of marks on the notepads for the Normal and Optional FPS conditions. An average of 0.5 marks were made on the notepad in the Normal condition and an average of 1.1 marks were made on the notepad in the Optional FPS condition. The small number of notes written suggest that either participants did not think writing information down was necessary or that using the notepad would have required too much work and so it was not used very often. Notes often referred to information that was not normally required but was needed to operate within the DYSIM, for example, the sector number receiving a hand-off.

In addition to the notepad, participants could compensate for reduced FPS posting and marking requirements by utilizing available computer functions such as the FPR or route display. The number of compensatory actions was analyzed using a 2 (Normal vs. Optional FPS)  $\times$  4 (FPR, route display, J-ring, slant-0) within-subjects MANOVA. No significant differences in the number of compensatory actions between the Normal and Optional FPS conditions were found. Apparently, participants did not make significant changes in their behavior to compensate for the reduction in FPS activity as evidenced by their lack of writing on the notepads and use of computer-based functions. Although not statistically significant, one warning about the optional procedure is that, with exception of individuals in high altitude sectors, participants tended to use slightly more FPRs in the Optional FPS condition than in the Normal condition. Compensatory behavior data are shown in Tables 2-4.

**Table 2. Compensatory Behavior: Means (Standard Deviations) for Individual Participants by Sector Type and Condition**

Sector	Condition	FPR	Route Display	J-ring	/0
Low	Normal	2.75 (3.58)	2.00 (1.31)	1.50 (2.07)	9.13 (4.49)
	Optional FPS	4.75 (8.03)	2.75 (1.83)	1.63 (1.60)	9.63 (3.85)
High	Normal	2.75 (4.40)	4.50 (1.60)	0.63 (0.92)	10.38 (9.24)
	Optional FPS	1.75 (1.58)	5.75 (3.06)	0.00 (0.00)	10.00 (7.31)

**Table 3. Compensatory Behavior: Means (Standard Deviations) for Team R-side Participants by Sector Type and Condition**

Sector	Condition	Point FPS	Point PVD	Request Info	FPR	Route Display	J-ring	/0
Low	Normal	0.25 (0.46)	2.63 (1.85)	2.38 (1.30)	1.88 (2.30)	1.50 (1.07)	1.63 (1.60)	9.88 (4.97)
	Optional FPS	0.13 (0.35)	1.50 (1.31)	2.38 (2.77)	2.88 (3.09)	1.50 (1.41)	1.50 (1.51)	8.25 (4.46)
High	Normal	1.75 (2.19)	2.25 (1.91)	1.00 (1.20)	2.00 (1.51)	2.75 (1.28)	1.13 (1.89)	13.50 (5.04)
	Optional FPS	0.13 (0.35)	2.00 (1.69)	1.25 (1.04)	4.75 (4.43)	3.75 (2.49)	1.33 (2.26)	13.50 (6.02)

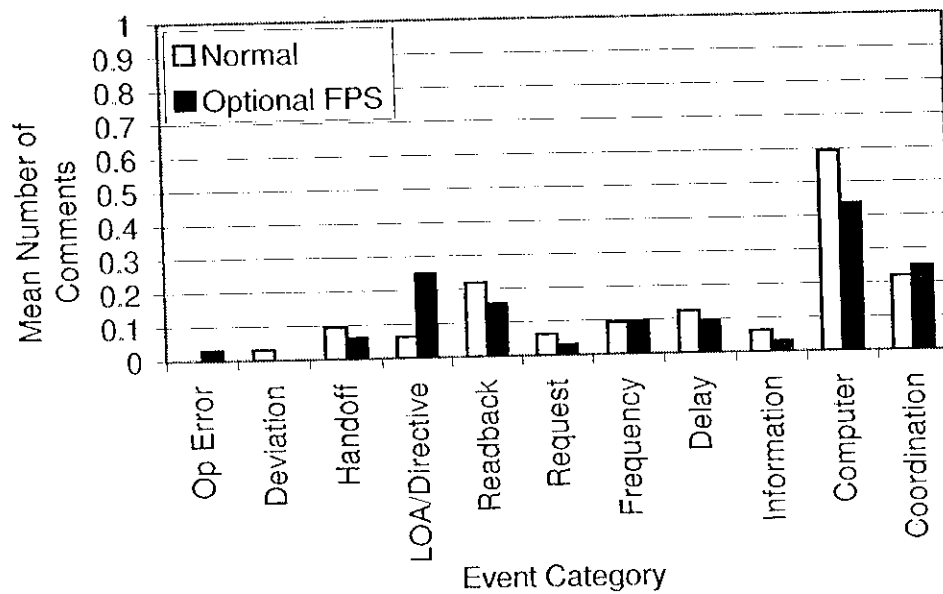
**Table 4. Compensatory Behavior: Means (Standard Deviations) for Team D-side Participants by Sector Type and Condition**

Sector	Condition	Point FPS	Point PVD	Request Info	FPR	Route Readout	/0
Low	Normal	2.75 (1.83)	2.00 (1.41)	0.38 (1.06)	0.50 (0.76)	1.25 (1.16)	0.00 (0.00)
	Optional FPS	1.75 (1.67)	2.50 (2.98)	0.25 (0.46)	1.00 (1.31)	0.88 (1.36)	0.13 (0.35)
High	Normal	3.25 (2.31)	1.63 (0.92)	0.50 (1.07)	1.38 (0.74)	3.25 (3.11)	0.25 (0.71)
	Optional FPS	3.63 (2.67)	3.75 (2.31)	1.13 (1.25)	3.38 (2.92)	2.63 (3.46)	0.38 (1.06)

### Subject Matter Expert observations

An SME for each sector used the Behavioral and Event Checklist to record the occurrence of 11 types of events including operational errors, operational deviations, missed handoff, violation of a Letter of Agreement or other directive, missed readback error, failure to grant request, failure to direct aircraft to switch frequency, cause unnecessary delay, inappropriate request of information, computer entry error, and failure to complete proper coordination. Subject matter experts selected these particular events as types of events that may have a negative impact upon operations, especially during the Optional FPS condition. These results are shown in Figure 6. Events on the checklist seldom occurred, but when one did it was just as likely to occur in either experimental condition. One operational error<sup>7</sup> did

<sup>7</sup> Aircraft must be separated by 5 nautical miles (nmi) laterally or 1,000 feet verti-



**Figure 6.** Mean number of occurrences of behavioral events collapsed over staffing conditions and sector types.

occur for a controller team in a high altitude sector but the error was, according to the SME, not related to FPS activity. Overall, the Behavioral and Events Checklist did not detect any significant differences between the Normal and Optional FPS conditions for number and type of events that occurred.

Like behavioral events, it was possible that the Optional FPS condition might impact team communication effectiveness and the adequacy of position relief briefings. On the contrary, these measures showed no differences between conditions. Team communication, as noted by our SMEs, was not adversely impacted. Only one negative comment was made by an SME regarding team communication. However, this comment occurred during the Normal condition and was related to participants having to repeat an action unnecessarily. Position relief briefings did not suffer either. The SMEs did not note any deficiencies regarding position relief briefings in either the Normal or Optional FPS condition.

### Post-experimental questionnaire

Data from the post-experimental questionnaire are shown in Table 5. Virtually all of the concerns regarding realism referred to situations that were imposed by the idiosyncrasies of the DYSIM facility or to

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cally when flying below 29,000 feet mean sea level (MSL). When flying at, or above, 29,000 feet MSL aircraft must be separated by 5 nmi laterally or 2,000 feet vertically. An operational error occurs when two or more aircraft violate these separation standards.

**Table 5. Percentage of Participants by Group Responding "Yes" to Items on the Post-experimental Questionnaire**

	Individual		R-side		D-side	
	Low	High	Low	High	Low	High
Did you notice anything unusual or unrealistic about either of the scenarios?	75.0%	25.0%	87.5%	25.0%	37.5%	37.5%
Were the scenarios similar in complexity?	50.0%	100.0%	87.5%	75.0%	50.0%	37.5%
Did the pilots or team member do anything strange?	25.0%	0.0%	0.0%	37.5%	25.0%	12.5%
Did responding to the workload rating hinder your ability to control traffic?	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Did you prefer the optional strip marking procedure?	75.0%	100.0%	75.0%	75.0%	87.5%	62.5%
Did you prefer the optional strip posting procedure?	87.5%	75.0%	62.5%	75.0%	87.5%	62.5%

unfamiliar traffic patterns. For example, participants commented on slow rates of climb for military aircraft. One ZJX participant commented that "U.S. Air never goes to Raleigh and Delta never goes to Charlotte." Another ZJX participant commented, "Delta doesn't land in Fayetteville." Although each pair of scenarios used were constructed and evaluated by SMEs to be similar in complexity, some participants perceived the scenarios they controlled as being similar in complexity, while others did not. Likewise, some participants mentioned that either their counterpart (R-side or D-side) or a simulation pilot had done something out of the ordinary during the experiment. None of the participants indicated that the WAK measure interfered with their ability to control traffic. Finally, many of the participants reported that they preferred the optional posting and marking procedures.

## CONCLUSIONS

Overall, participants at ZOB and ZJX posted fewer FPSs and made fewer marks on those that were posted during the Optional FPS condition. Even though FPS activity was reduced in the Optional FPS condition, no detrimental effects in performance, workload, position relief briefings, or team communication were observed. It is important to note that participants performed similarly in both experimental conditions despite never having practiced using the optional FPS posting and marking procedure prior to the experiment. According to the post-experimental questionnaire, most participants preferred the optional FPS marking and posting procedures they used during the Optional FPS condition. Participants did not compensate for the lack of FPSs by using other tools to obtain or remem-

ber information that would have otherwise been present on an FPS. No detrimental effects of the Optional FPS condition were detected. Therefore, the results of the present experiment suggest that the Optional FPS condition provided a viable procedure by which FPS activity could be reduced.

The Optional FPS procedure should be investigated in a variety of other scenarios including situations where radar capabilities are diminished or lost. Additional testing should also be conducted using scenarios that participants perceive as being relatively high in workload. Although the experiment did not use DSR consoles, any reduction in FPS activity observed with the M-1 console should also be realized using DSR. It cannot be concluded from this experiment that the Optional FPS procedure will adequately address any space restrictions of the DSR. However, it can be concluded that space restrictions in DSR will be less of an issue with the Optional FPS procedure than without it.

## APPENDIX

Proposed change to Order 7210.3M Part 2. Chapter 8. Section 1. Paragraph 8-1-6. Flight progress strip usage/marking procedures.

- a. Flight progress strips will continue to be posted, marked, and updated in accordance with the National directives until radar contact and communications are established and accepted.
- b. Once this has been achieved, the radar controller (or, if so designated, the manual controller) may remove the strip from the board. If the radar controller (or, if so designated, the manual controller) elects to keep the strip at the sector, a check mark may be placed in box 21-24 to indicate that further strip marking is unnecessary.
- c. The sector team is responsible for all information contained on the flight progress strip. Standard strip marking is optional for both controllers. However, if the radar controller chooses to utilize standard strip marking, the associate controller will support and comply with that request. If the radar controller does not choose to utilize standard strip marking, nothing in this procedure precludes the associate controller from utilizing standard strip marking.
- d. Partial recording of control information deemed useful to the sector operation is permitted.
- e. Strips on aircraft "pointed out" to the sector may be check marked even though communications are never established.
- f. The following flight progress strips are to remain posted and standard strip marking used:

- (1) Any aircraft you cannot reasonably expect to remain in radar contact.
- (2) Aircraft transitioning from radar to non-radar environment.
- (3) Aircraft requiring special handling, i.e., emergencies, radio failures, etc. (Note: Standard strip marking will begin when the need for special handling is identified.)
- (4) All non-radar flights.
- (5) All flights transitioning from automated to non-automated modes of operation.
- (6) All flights that are issued holding instructions.
- g. Departures and proposals are to be considered non-radar until radar contact has been established and accepted in accordance with FAAH 7110.65.
- h. Any control action not recorded via landline, frequency, or computer entry must be marked on the appropriate strip to record the action.
- i. In the event of a back-up system failure, the strips will be posted and marked in accordance with National and local directives. These systems would include any back-up radar or malfunctioning recording system and when operating in DARC only.
- j. The controller will continue to be responsible for the control of the aircraft and coordination of information as prescribed in FAAH 7110.65.
- k. Blank note pads will be available at every sector for the controller's use.
- l. Standard strip marking must be accomplished when training is in progress. This may be discontinued with the consent of the training team.

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## ACRONYMS

$\alpha$	Alpha
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
CRD	Computer Readout Device
DARC	Discrete Address Radar Channel
D-side	Data Side
DSR	Display System Replacement
DYSIM	Dynamic Simulator
FAA	Federal Aviation Administration
FPL	Full Performance Level
FPR	Flight Plan Readout
FPS	Flight Progress Strip
$M$	Mean
MANOVA	Multivariate Analysis of Variance
NASA	National Aeronautical and Space Administration
NATCA	National Air Traffic Control Association
PVD	Plan View Display-
R-side	Radar Side
RT	Reaction Time
SA	Situation Awareness
$SD$	Standard Deviation
SME	Subject Matter Expert
TLX	Task Load Index
WAK	Workload Assessment Keypad
ZJX	Jacksonville ARTCC
ZOB	Cleveland ARTCC

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